

An Investigation of the Wave Boundary Layer and Its Interaction with the Atmospheric Surface Layer

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LONG TERM GOALS

The goal of this research is to gain a better understanding of the flow characteristics of the marine surface layers, including the coupling at the air-sea interface. Specifically, the research focuses on the influence of ocean waves on turbulent processes, especially those involved in stress-wave interactions. The long range goal of this research is to develop new and/or revise old theoretical descriptions of turbulence, such that they are universally applicable to both over land and over sea boundary layers. This is to be accomplished by focusing on the physical processes unique to the marine boundary layers through a combination of scale analysis and numerical modeling.

OBJECTIVES

The PI's first objective is to improve our understanding of flux profile relationships over the ocean using our profile measurements in the kinetic energy, momentum, and scalar variance budget equations. This involves an investigation of the applicability of Monin-Obukhov (MO) similarity theory to over-ocean measurement in order to determine these functions and their proportionality factors (e.g., the von Karman and Kolmogorov constants). That is, the goal is to determine these functions over the open ocean where a difference with land derived functions is possible due to the fluid ocean surface. The PI's second objective in this research is to investigate how the wave induced flow affects the turbulent processes in the marine surface layer. In these studies the PI will focus on the role that stress/wave interaction plays in modifying the magnitude and direction of the momentum flux within the wave boundary layer (WBL).

APPROACH

The Marine Boundary Layers (MBL) Accelerated Research Initiative centers around two field programs designed to examine the 3-D structure of the marine boundary layers: the Risø Air-Sea Experiments (RASEX) conducted in shallow water off the coast of Denmark, and the MBL Main Experiments conducted in deep water off the California coast. In these experiments we deployed fast response and mean sensors to investigate the vertical structure of the atmospheric surface layer (lowest 10% of the marine boundary layer). The overall structure of the atmospheric boundary layer is being investigated by coupling these measurements with remotely sensed variables (e.g., lidar, wind profiler, and sodar)

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and rawinsonde launches. Horizontal variability is being investigated by combining all of the above with data taken from research vessels, microwave radars, and a research aircraft. The oceanic boundary layer is being investigated with a similar set of instrumentation, including sonars, drifting buoys, current meters, towed instruments and vertical profilers. These two boundary layers are then coupled together using simultaneous measurements of the wave field. This involved the deployment of wave-wire arrays and remote sensing instrumentation on both sides of the interface.

Our approach has involved the decomposition the measured signals into mean, wave-induced, and turbulent components. The techniques we are using to decompose the signal involves traditional phase averaging as well as more sophisticated approaches involving Hilbert transforms and a new similarity theory involving wave-pressure and wave-velocity correlations. The separation of the flow into wave-induced and turbulent components simplifies the interpretation of the data by allowing us to study the processes separately.

WORK COMPLETED

The collaborative work between the PI and Carl Friehe, Scott Miller, Tihomir Hristov (UC-Irvine), and Suzanne Wetzel (Univ. of Wisc.) has resulted in the submission of several articles to the *Journal of Physical Oceanography* and to the Conference on Wind-Over-Wave Couplings: Perspectives and Prospects over the past year. These investigations are summarized in the results section given below.

RESULTS

Our investigation of MO similarity demonstrated that the theory is valid in the marine surface layer as long as it is applied to turbulence statistics taken above the wave boundary layer (*Edson and Fairall*, 1998). This study found that the TKE budget is well described by a balance between production and dissipation except for slightly unstable conditions where production exceeds dissipation by as much as 17%. We have argued that this is due to a local imbalance between the pressure and energy transport. Over developing surface waves, part of the energy flux entering the surface layer is not dissipated into thermal energy, but rather is transported to the surface to generate and sustain waves and currents. This energy flux is expected to result in a “dissipation deficit” in the volume-averaged dissipation rate that would result in local production exceeding dissipation. We would expect the dissipation deficit to be greatest over the youngest seas where the energy flux is largest. Evidence for this effect is given by *Edson et al.* (1997), which showed that the younger the seas the greater the deficit.

The challenge is to derive parameterizations that account for the flux of kinetic energy into the ocean as a function of sea state. We are currently working on the hypothesis that observed dissipation deficit is due to a pressure transport term that is sea-state dependent. This proposition seems reasonable since the pressure flux evaluated at the surface, represents the energy flux into the waves. In our initial investigations, the RASEX data is being used to directly study the role of the pressure transport term in the turbulent kinetic energy equation (*Wilczak et al.*, 1998). The combination of the surface slope and pressure sensor measurements have allowed us to directly measure the component of the momentum flux associated with form drag. The doctoral research conducted at WHOI by Dr. Jeffrey Hare resulted in a new similarity theory involving wave-pressure and wave-velocity correlations (*Hare et al.*, 1997). This work has provided a better understanding of the complex vertical structure of momentum and energy exchange in the WBL.

The FLIP measurements are now being used to study the influence of waves on the transport of energy (*Edson et al.*, 1997) and momentum (*Miller et al.*, 1998) to and from the ocean surface. In particular, we are investigating the influence of the dominant, wind-driven, surface waves on the vertical flux of horizontal momentum in the marine surface layer over open ocean conditions. Investigations with our students of the vertical structure of the WBL have led to new techniques to describe the behavior of near surface turbulence by decomposing the measured signals into mean, wave-induced, and turbulent components using traditional phase averaging (*Wetzel et al.*, 1998), and more sophisticated approaches involving Hilbert transforms (*Hristov et al.*, 1998). Once the signal has been decomposed, the wave-induced component of the horizontal and vertical can be combined to provide vertical profiles of the wave-induced momentum flux. These results are now being used to investigate both the magnitude and sign of this flux as a function of sea state. For example, the study conducted by *Wetzel et al.* (1998) showed a wave-induced momentum flux to the waves in developing seas and a flux from waves to wind over decaying seas.

IMPACT/APPLICATIONS

These results have had a profound impact on the modeling community. As a result, we have been asked to give briefings and seminars on these results at the Naval Research Laboratory in Monterey and at the National Center for Atmospheric Research in Boulder. The results are also impacting the way that researcher interpret the measurements taken from ocean observing system. For example, it has been long known that flux estimates from indirect methods require additional parameterizations to account for wave-induced effects. Our MBL investigations are now providing a clearer picture of the physical processes in the wave boundary layer responsible for effects.

TRANSITIONS

None

RELATED PROJECTS

The work involved in the MBL ARI nicely complements the research objectives of our involvement in the NSF's Coastal Ocean Processes Study. Our component of this program is aimed at investigating the role of surface waves and atmospheric forcing in air-sea gas exchange. Sean McKenna, a WHOI/MIT Joint Program student, is using an AASERT to investigate the role of surfactants in air-sea interaction. Preliminary results from this effort will be given at the AMS meeting in Dallas (*Edson et al.*, 1999). The MBL program is also providing important information to the Coastal Mixing and Optics (CMO) ARI. The FLIP measurements have greatly assisted the PI in interpreting the data he collects from a sonic anemometer mounted on the central mooring of the CMO array. In particular, the FLIP analysis has allowed the PI to adjust his inertial-dissipation estimates of the momentum flux to take into account some of the influences of the wave-induced flow. The results from the two programs have been combined in a Master's thesis by *Martin* (1998), a naval student in the WHOI/MIT Joint Program.

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IN-HOUSE/OUT-OF-HOUSE RATIOS

100% of this work was completed out-of-house by the PI at the Woods Hole Oceanographic Institution.